ENGINEERING CASE LIBRARY

ECL 211

THE (Delinquent) DRAWBAR (A)

A study of the circumstances surrounding an accident involving a tank train hauling gasoline. The train overturned on an exit ramp from an interstate highway, caught fire and burned, completely destroying the tank train and cargo. A key question was whether the drawbar between the semi-trailer and full trailer broke after the start of the accident or whether it broke before the accident and thus was the initiating cause.

Appreciation is expressed to Mr. S. A. Garzia of Vandeveer, Doelle, Garzia, Tonkin & Kerr and to Mr. W. D. Booth of Plunkett, Cooney, Rutt & Peacock, both law firms of Detroit, Michigan, for the privilege of using their files in writing this case study in failure analysis.

 This case history was presented at the 1974 Annual Reliability Maintainability Symposium. Published with support from the sponsors of the ASEE-Stanford Engineering Case Program:

E. I. du Pont de Nemours and Company
The General Electric Foundation
IBM
Olin Corporation Charitable Fund
Union Carbide Corporation

The Circumstances

One beautiful August morning a truck driver was hauling gasoline in a rig consisting of a tractor, semi-trailer, and a full trailer (pup). A drawbar provided motive force between the semi-trailer and the pup. The driver was on the exit ramp from in interstate highway about 7 am when the rig tipped over to the right, caught fire and was completely destroyed with all the cargo. The driver was unhurt. Post-accident examination showed the drawbar was broken but the safety cables were intact. The owner of the nine month old rig entered suit against the manufacturer of the rig (which included the drawbar) for recovery of about $55,000 covering loss of both rig and cargo. His claim was based on the allegation that a defective drawbar led to the accident.

Observations

The accident occurred at the intersection of I-94 and U. S. 27 as indicated in Figure 1. The driver was west-bound on I-94 and was on the exit ramp when the rig overturned and burned. It was daylight with clear and sunny weather. The ramp was concrete and dry with no significant defects. The train overturned at a distance of 300-400 ft. from U. S. 27. The ramp has a radius of about 300 ft. with a slight up-grade at that point.

The driver was familiar with the area and was aware that he would have a stop sign when he reached U. S. 27. He had been driving trucks for about 30 years and had an excellent driving record. He claimed to be going about 30 mph where the suggested ramp speed was 40 mph. The State Highway Patrol report, however, indicated the speed may have been too fast. This report also had the driver's comment that "as he rounded curve it felt like he was pulled to right and then tipped over." The driver was downshifting from 7th or 8th gear in the curve.

Tire marks were visible on the pavement. Marks in the middle of the road were quite regular while, to the right, dual wheel marks were visible which indicated a "skipping" or "jumping" motion.

The semi-trailer and pup were coupled by a drawbar which was carried by the pup and attached to the semi-trailer by a pintle hook. Safety cables were provided and were crossed between the semi-trailer and the pup. When properly coupled, there was about 26 inches between the trailers. The semi-trailer was full with 9000 gallons of gasoline. The pup had only 1000 gallons in the middle compartment rather than the 7000 gallons possible.

Plaintiff's Argument

A mechanical technical expert (Mr. A), retained by the plaintiff, was of the opinion that the cause of the accident was the failure of the drawbar between the semi-trailer and the pup. It was his opinion that the failure was a progressive one which resulted from inadequate design, poor quality welds, and poor quality castings in the drawbar.

Mr. A indicated that stresses in excess of the yield stress cause slight cracks or ruptures which grow under successive loadings to the point where catastrophic failure occurs under approximately normal loading. In this case, the load causing final failure could have been caused as the driver braked to slow down for the curve ahead of him.

As a further consequence, Mr. A believed that the lug on the right side of the drawbar broke first at about the point where skidmarks (some 220 ft. long) started. These skidmarks were caused by the front wheels of the pup as it was pulled along with its front wheels turned sharply to the right. This position of the front axle was due to the pull of the lug on the left side of the drawbar which rotated the axle about the king-pin up to the limit of the safety cable connected between the left rear of the semi-trailer and the right front of the pup.

The left lug of the drawbar failed at the end of the skidmarks. Both safety cables were then operative and straightened the front wheels of the pup. During skidding, however, the tendency of the pup to turn right would have pulled the rear end of the semi-trailer out of line to the right. As the driver downshifted, the drawbar pull ceased and the pup was guided by its front wheels. This swung the front end of the pup to the right and into the rear of the semi-trailer which was already out of line to the right. This impact, combined with the skidding, tipped the semi-trailer over carrying the tractor with it. The pup followed.

A metallurgist (Mr. B), retained by the plaintiff, found that the drawbar was built-up of tube, plate, and castings welded together as shown in Fig. 2. The steel casting in the vicinity of the fracture had a ferritic matrix with a fine lamellar pearlite. The tube was a low carbon steel having pearlite in a ferrite matrix. These were reasonable structures. Considerable recrystallization was observed at the weld interface and through the heat-affected regions.

Fig. 2b is the editor's sketch of the configuration of the drawbar.

Fig. 1: Intersection of E-W I-94 and N-S U.S. 27, looking southward. Circle indicates location of tank train after overturning and catching fire.

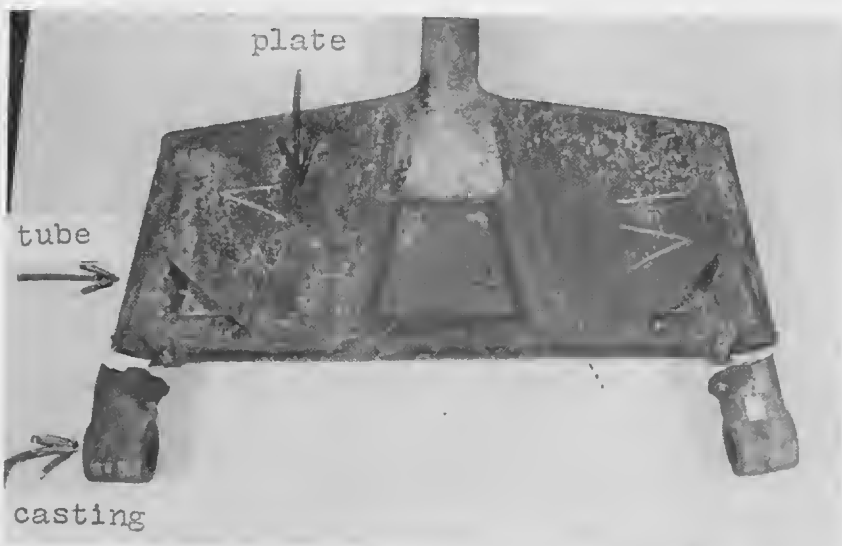
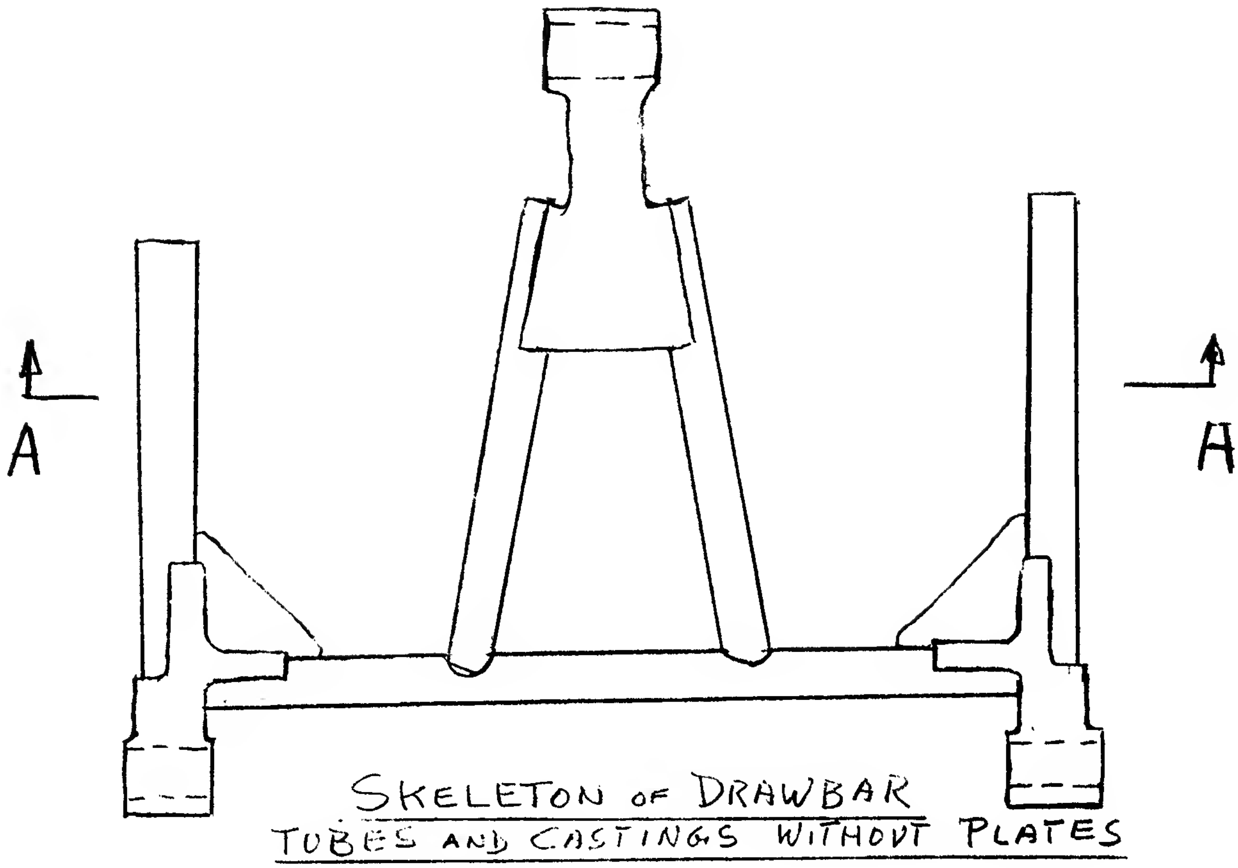


Fig. 2: Overall view of drawbar showing the component plates, tubes, and castings welded together. The two failed castings are shown in approximately their respective locations.

About one-ninth size.



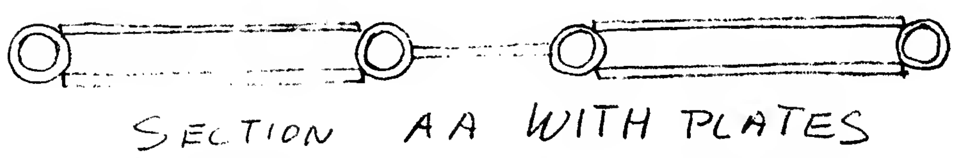


Fig. 2a

Editor's sketch of the configuration of the drawbar.

Figure 3 is a close-up view of the two fracture surfaces at the right side of Fig. 2. Figure 4 is a still closer view of the fracture surface of the casting (lug). The break is through the weld between tube and casting (top of Figure 4) and through the casting (bottom of Fig. 4). The casting was of poor quality as rather large pores (or shrinks) are abvious at the bottom of Fig. 4. There was also evidence of further pososity but with smaller size pores. It was doubtful that the manufacturer had x-rayed these castings before assembly since voids of this size would certainly have been detected. He should have been conscious however, of possible questionable quality since there had been some surface welding repair work on both of the castings.

A section through the weld between tube and casting is shown in Fig. 5. Fig. 6 shows an enlargement of a portion of this weld. Fig. 5 shows the heat-affected zones and lack of penetration of the weld. The lack of penetration is still more evident in Fig. 6.

Mr. B. concluded that both the castings and the welding were inferior and thus the basic cause of failure in the drawbar was poor quality workmanship. He believed that the failure started at the weld between the tube and casting. Despite Mr. A.'s comments on progressive failure (indicating a fatigue failure), he could find no evidence on visual examination which conclusively supported this view.

Defendant's Argument

The defendant denied the claim for property damage and related damages. There was admission that the castings were poor quality. It was further admitted that there was a question of the quality of the welding. At the same time, however, it was contended that that particular part of the drawbar was considerably overdesigned. Thus, any reduction in effective load carrying area would be offset by the overdesign.

The defendant's expert, Mr. C., a metallurgist, found that microscopic examination of the fractured surfaces revealed a very sharp fracture but no distortion of the metallic grains which indicated to him that breaking had occurred under a suddenly applied load.

It was Mr. C.'s opinion that the tank train was in proper operating condition going uphill on the exit ramp. He believed the driver was going too fast and suddenly applied his brakes, causing the "skipping" skidmarks, thus helping the tank train to overturn. At that point, the twisting load imposed on the drawbar caused it to break at the weakest point.

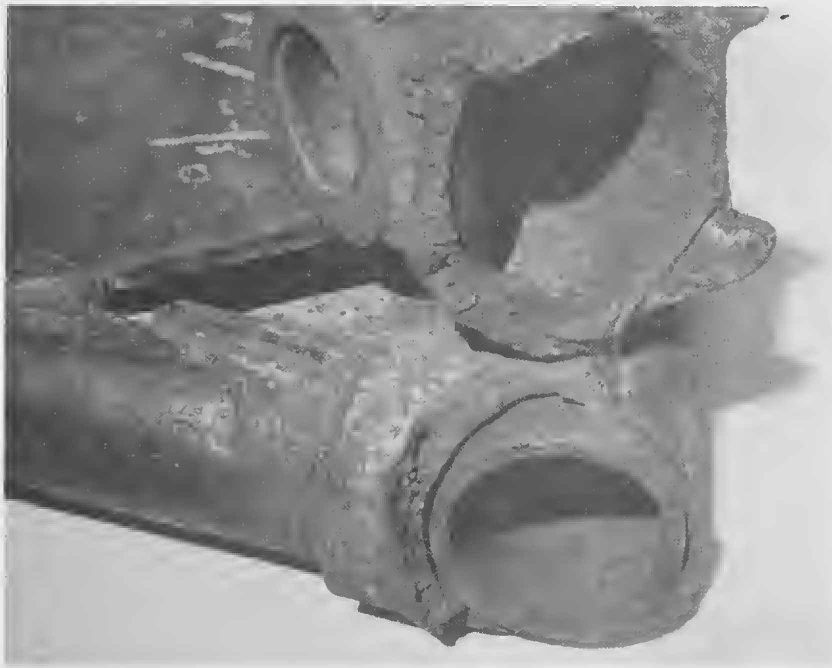


Fig. 3: Fracture on right side of Fig. 2 at the joint between the tube and casting. Broken casting is placed on top to show matching of the two halves.

About one-half size.

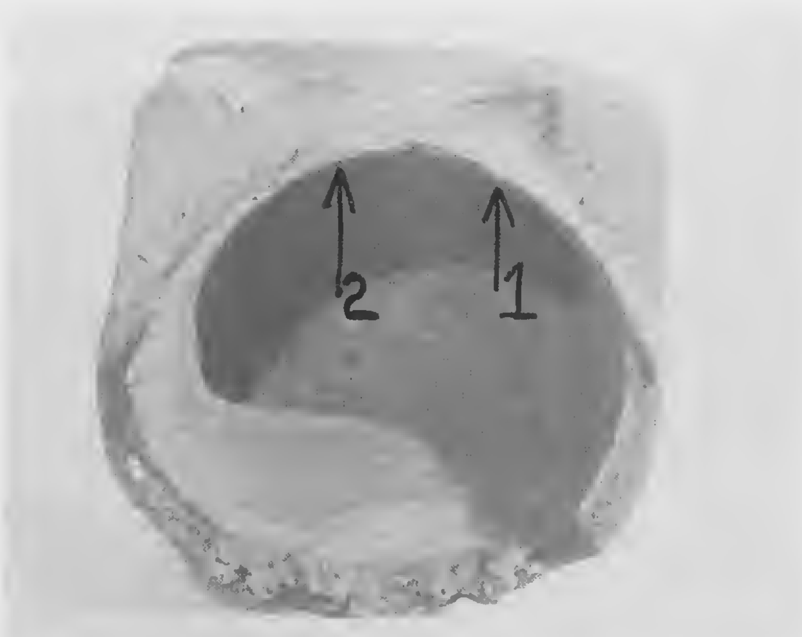


Fig. 4: View of fracture surface of casting from right side of Fig. 2. Weld is at top. Extensive voids and porosity are visible at bottom.

About full size.

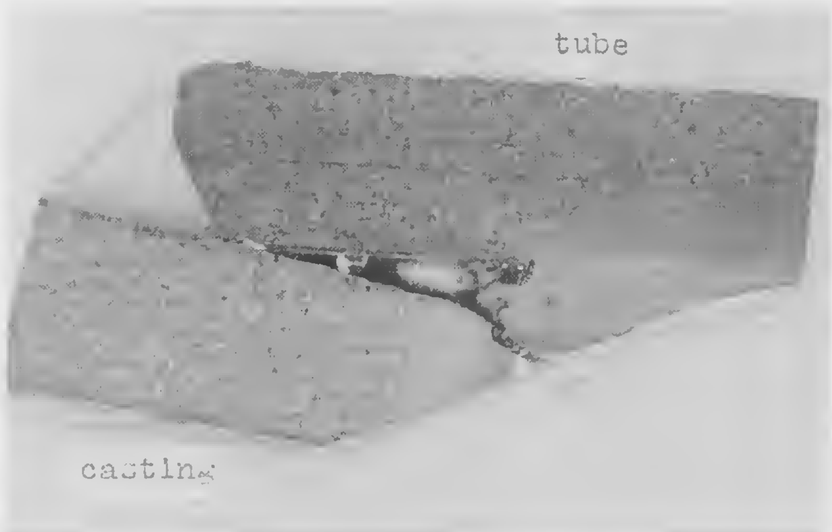


Fig. 5: Section of joint between tube and casting, showing weld deposit, heat affected zones and low weld penetration. 2% Nital etch. 4.5 X

Fig. 6: Portion of the joint shown in Fig. 5 between casting and tube at the weld showing poor weld penetration. 2% Nital etch. 50 X

The defendant cited the reports of both Mr. B. and Mr. C. as providing no evidence of progressive failure and thus concluded that failure was "instantaneous".

The defendant's position was that the overturning forces were already in effect before any fracture of the drawbar occurred. He further contended that the overturning forces were due to the driver being unable to negotiate the curve due to the velocity of the rig with a further contribution to loss of control from sudden application of the brakes. Thus, he contended that the speed of the rig was the proximate cause of the upset.

QUESTIONS:

1. It is obvious that there are substantially different interpretations of the evidence by the plaintiff and defendant. What is your analysis of the situation, i.e., what is your hypothesis of the cause of failure and the sequence of events involved?

2. On the basis of your hypothesis, how do you think the lawsuit should be settled?

3. What additional work would you perform to verify your hypothesis?

4. If a part is indeed "overdesigned", does it follow that the part will not fail? Why?

THE (Delinquent) DRAWBAR (B)

Further Evidence

It was obvious that some additional evidence was required to resolve the difference in positions of the plaintiff and defendant.

Mr. B. then conducted an examination of both broken castings using electron microscopy. Much of the fracture surface through the weld was examined. Figure 7 shows a portion of this surface in the position indicated by arrow 1 (Fig. 4). "Parallel" striations are clearly visible. These striations are characteristic of fatigue failure (progressive failure) since the striations show the advance of a crack front from one cycle of loading to the next. Figure 8 shows a typical portion of the fracture surface in the position indicated by arrow 2 (Fig. 4). The black dots are due to corrosion products. This indicates failure in this region well in advance of the final failure.

Figure 9 is representative of the fracture surface of the left casting. This is a typical cleavage failure. No evidence was found of fatigue striations or corrosion. This does not say, however, that none existed in the left hand casting.

Probable Cause of Failure

It was the contention of the plaintiff that there was partial failure in the drawbar prior to the final failure. It was contended that this fatigue failure originated from poor quality workmanship in welding the drawbar. The poor quality of the castings was a contributing factor. This supports the hypothesis of failure of the right side followed by failure of the left side of the drawbar.

Outcome of the Lawsuit

The case went to trial. Attorneys for both sides were willing to settle out of court, but the principals could not agree on the amount. Testimony was taken from the driver, the chief engineer of the defendant corporation, and all three technical witnesses. Before trial resumed on the fourth day with Mr. C. still on the stand, a settlement agreement was reached with the defendant paying $35,000.

Possible Protective Action by the Manufacturer

Following the accident, improved welding procedures and inspection procedures were instituted. The chief engineer had testified at the trial that there were no inspection procedures at the time of manufacture as there had been complete reliance on the reputation of the foundry which made the castings.

Fig. 7:
Region of fracture surface in weld at location shown by arrow 1 in Fig. 4. The striations in the figure indicate a progressive or fatigue failure as the lines represent the movement of the crack front under successive load applications.

20,000 X

Fig. 8:
Region of fracture surface in weld at location shown by arrow 2 in Fig. 4. The black dots are corrosion products which indicate that this surface had failed well in advance of the final failure.

6000 X

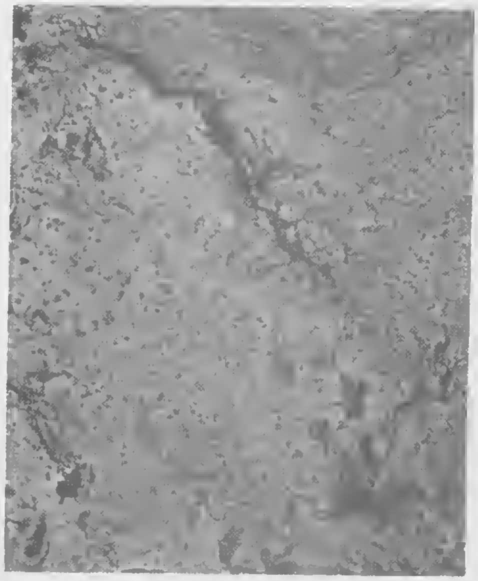


Fig. 9:
Region of fracture surface in weld in left hand casting. This is a typical fracture surface which failed by cleavage in a brittle manner. It is representative of the left hand casting.

6000 X